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Impact of activator incorporation on red emitting rods of $ZnGa_2O_4:Cr^{3+}$ phosphor

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ABSTRACT

Chromium doped zinc gallium oxide ($ZnGa_2O_4:Cr^{3+}$) microrods were synthesized by simple solid state reaction method. The transformation on crystal structure and optical properties with molar concentration of Cr^{3+} were analyzed. The cubic spinel nature of $ZnGa_2O_4:Cr^{3+}$ phosphor and their crystalline nature were confirmed from x-ray diffractogram. The average grain size of the samples range between 24 and 29 nm, with lattice parameter values greater than that of bulk. Lattice strain produced in the lattice on doping was estimated from the Williamson–Hall plot. It increases on Cr^{3+} doping up to 3 mol% and then decreases. Rod like nature of zinc gallate was observed from the surface morphological analysis using SEM. X-ray photoelectron spectroscopy was used for the chemical state identification of the constituent elements in the compound. The photoluminescense spectra consists of various emission lines originated from the chromium ion in the spinel lattice. The purity of red emissions were observed from chromaticity diagram with a concentration quenching initiated from the dipole–dipole interaction, with increase in dopant concentration. Band gap of the samples were estimated using Kubelka-Munk equation which exhibited red shift compared to bulk due to band tailing effect.

1. Introduction

Zinc gallium oxide [$ZnGa_2O_4$] is a well-known oxide semiconductor having wide band gap, leading to the elevated optoelectronic applications. The role of this spinel oxide in the field of display devices is widespread from earlier times. It is also a good transparent conducting oxide having enhanced photovoltaic applications [1–3]. The improvements over sulfides, makes it suitable for the enormous range of applications. This self-activated blue phosphor can be tuned to a green and red phosphor by doping with suitable activators like Mn^{2+}/Tb^{3+} and Cr^{3+}/Eu^{3+} respectively [4–6]. $ZnGa_2O_4:Cr^{3+}$ is a good red emitting phosphor, where the Ga^{3+} ions are replaced by Cr^{3+} ions as depicted in Fig. 1. This red oxide phosphor is now renowned by its feature of persistent luminescence [7,8]. It is an optical phenomenon whereby, long running emission, mainly in visible range is observed from a material even after the termination of irradiation. The defects present in the host materials are responsible for this phenomenon of afterglow, by trapping the charge carriers. There are several reports on persistent phosphors which are exploited in optoelectronic application [9–12]. However, $ZnGa_2O_4:Cr^{3+}$ is a much preferred material to study this phenomenon, due to the well resolved energy levels of Cr^{3+} and the simpler crystal structure [13]. Also there are reports on its better role as biomarker in in vivo imaging techniques, the detection of cancerous cells and drug delivery [14–16].

Various synthesis techniques like solid state reaction [17], sol gel [18], hydrothermal method [19], pulsed laser deposition [20] etc. were used for the synthesis of zinc gallate. Among the various synthesis techniques solid state reaction (SSR) retain its position, by disregarding all the drawbacks, in material synthesis. We are looking for such a common and simple method for the preparation of our phosphor. This is the most widely used method for the synthesis of polycrystalline bulk phosphors by providing large range of selection of starting materials like, oxides, carbonates, etc. SSR allows the solid reactants to react chemically without the presence of any solvent at high temperatures yielding a product which is stable and in more amount than a normal reaction can. The major advantage of SSR method is, that final product in solid form is structurally pure with the desired properties. Since SSR is a solvent free method, there is no waste to remove at the end of the reaction making this an environment friendly, cost less technique. Hence the final products do not require any purification to remove traces of solvent and impurities making the method more economic. Thus SSR has considerable importance in the rapidly emerging field of

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